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PROGRESS REPORT OF ACMRR AD HOC GROUP OF EXPERTS ON THE FACILITATION OF ACOUSTIC RESEARCH

A Survey of Extent and Status of Current Research

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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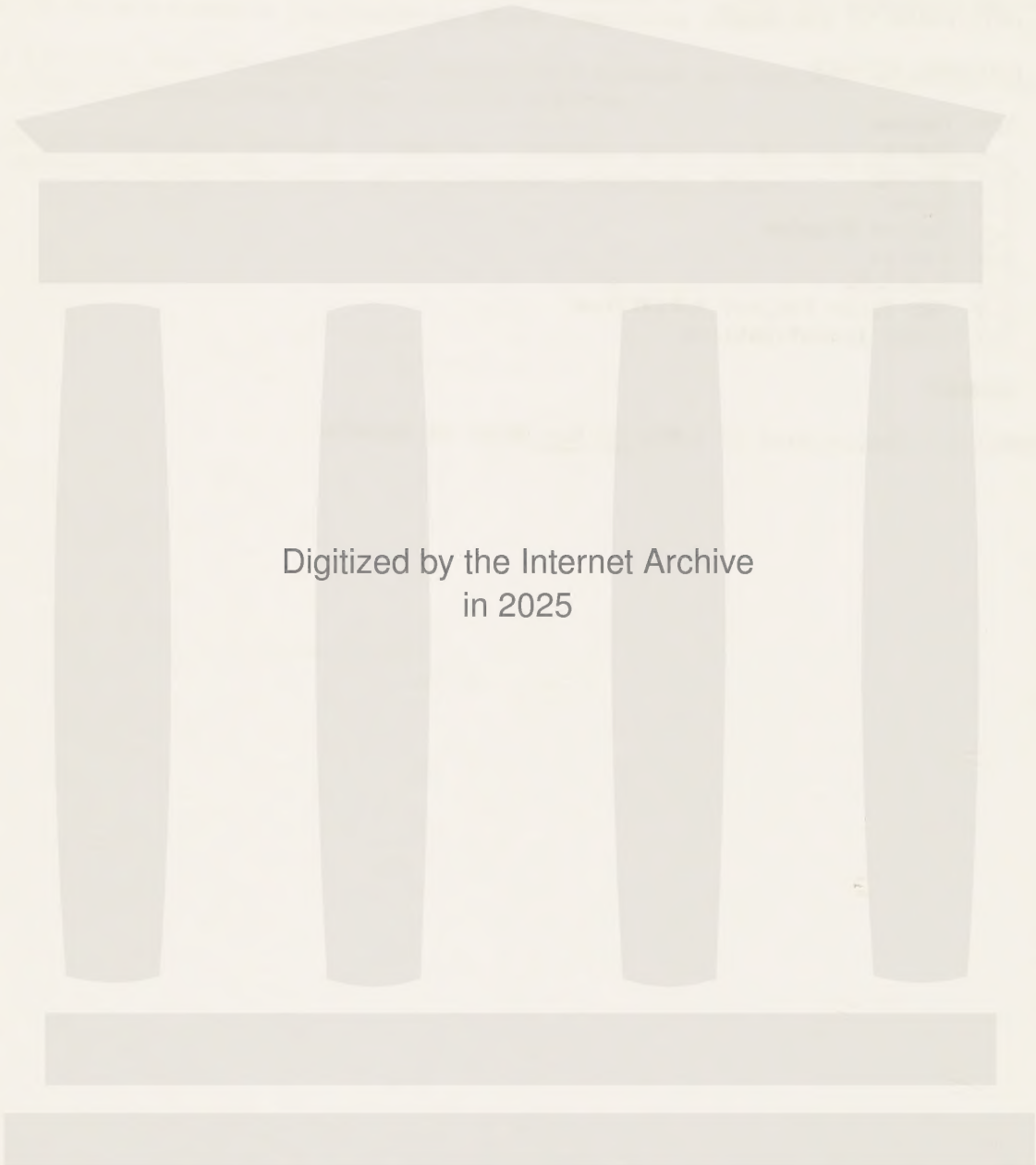

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1. INTRODUCTION

At its sixth meeting in Rome in March 1971, FAO's Advisory Committee on Marine Resources Research recommended that, in view of the rapid and important developments in the use of acoustic fish detection techniques in fish abundance estimation and other fisheries research projects, FAO should set up a panel of experts, drawn from the institutions engaged in research in this sphere, with the following terms of reference:

(i) To keep under review the work in progress on the development of specialized acoustic fish detection equipment and operational techniques and their application in fish abundance estimation studies.

(ii) To facilitate and coordinate the national research effort by identifying the limitations of the existing techniques and the principal lines of future research.

This recommendation was duly implemented by FAO with the establishment of an "Ad Hoc Group of Experts on the Facilitation of Acoustic Research", under the convenership of Mr. B.B. Parrish (U.K.), for which FAO would provide the Secretariat and with representation from the following countries: Federal Republic of Germany, Japan, Norway, Spain, U.K. (England and Scotland), U.S.A., U.S.S.R (for list of members see Appendix I).

2. ACTIVITIES OF THE GROUP

As a first step in the Group's work it was decided to undertake, by correspondence, a survey of the extent and status of the research in progress in each country on the use of acoustic techniques for fish abundance estimation in fish resources research. For this purpose, the members of the Group were requested to supply information for their countries relating to:

(a) the laboratories and research workers engaged in research on the use of acoustic fish detection equipment in fisheries research, with special reference to fish abundance estimation studies;

(b) the sea areas and species of pelagic and demersal resources on which the investigations are being conducted;

(c) the types of acoustic equipment currently used in the investigations or under development, including where appropriate specialized echo-counting systems;

(d) the current status of the methods and results achieved; main equipment and operational factors limiting reliability; and accuracy of current acoustic methods and future research requirements.

3. PROGRESS REPORTS

3.1 Canada

In Canada research in the use of acoustic fish detection equipment for fish abundance estimation is being conducted at laboratories of the Department of the Environment's Fisheries Research Board, in association with University departments, laboratories of the Defense Research Board and the manufacturing industry (in cooperation with personnel from the Fisheries Research Board Laboratories) and other sections of the Fisheries Service. Specific research centres undertaking these investigations include:

(i) Institute: Department of the Environment
Fisheries Research Board of Canada
Marine Ecology Laboratory
Bedford Institute
Dartmouth, Nova Scotia

Investigators: R.G. Dowd, S. Paulowich and others

Species investigated and sea areas: Groundfish species on the Scotian shelf and in the Gulf of St. Lawrence

Acoustic equipment: Digital echo-counting system, consisting of a towed transducer, a Simrad EK-50 Scientific Sounder linked to a Honeywell 316 computer (12K memory), for processing the sonar data on a real time basis

Status: Equipment successfully tested on numerous sea cruises. Development of system nearing completion; testing of special narrow beam transducer expected to be completed in 1973. Principal shortcoming of the system is its inability to handle high fish densities; i.e., densities in excess of one fish per insonified resolvable volume

(ii) Institute: Department of the Environment
Fisheries Research Board of Canada
Biological Station
Nanaimo, British Columbia

Investigators: F.C.H. Taylor and others

Species investigated and sea areas: Herring and secondarily dogfish and hake in the Straits of Georgia and in the Pacific off the lower west coast of Vancouver Island

Acoustic equipment: Simrad EK-38 Scientific Sounder and Simrad 580-5 Sonar, using echo integration system developed at the University of Washington (see U.S.A. report; Thorne, 1971)

Status: This system is currently under evaluation; no results yet available. Analogue echo counting may give more satisfactory results at higher fish densities than echo-counting systems but substantial errors may be incurred at high densities. Echo integration system requires careful calibration

(iii) Institute: Department of the Environment
Fisheries Research Board of Canada
Biological Station
St. Andrews, New Brunswick

Investigators: Groundfish research group

Species investigated and sea areas: Groundfish species on Nova Scotian Banks and Gulf of St. Lawrence

Acoustic equipment: Digital echo-counting system, consisting of a towed transducer, a Simrad EK-50 Scientific Sounder linked to a Honeywell 316 computer (12K memory), for processing the sonar data on a real time basis

Status: System under evaluation

(iv) Other Investigations

In addition to the above studies, other work in progress in Canada under contracts from Industrial Development Branch of Canadian Fisheries Service includes the following:

(a) Development of medium-range high speed 360°, electronically scanned sonar (LSS-30)

(b) Mathematical analysis of the sampling problem in echo sounding and the development of appropriate statistical bounds (MacNeill, 1971)

(c) Research is also in progress in a number of laboratories, including Defense Research Board establishments, on underwater sound propagation and scattering (Chapman et al., 1970; Scrimger and Turner, 1970; Mohammed, 1967)

(v) References

Chapman, R.P., O.Z. Bluy and R.H. Adlington, 1970 Geographic variations in the acoustic characteristics of deep scattering layers. In: Proceedings of an International Symposium on Biological Sound Scattering in the Ocean, Maury Center for Ocean Science. Washington, D.C., Department of the Navy, M.C. Report 005:306-17

MacNeill, I.B., 1971 Quick statistical methods for analysing the sequences of fish counts provided by digital echo counters. J.Fish.Res.Board Can., 28(7):1035-42

Mohammed, A., 1967 Calculation of the average backscattering coefficients of a scattering layer in a frequency band. J.Am.Statist.Assoc., 41:177-81

Scrimger, J.A. and R.G. Turner, 1970 The dependence of acoustic volume scattering on depth frequency and time in the Northeast Pacific Ocean. In: Proceedings of an International Symposium on Biological Sound Scattering in the Ocean, Maury Center for Ocean Science. Washington, D.C., Department of the Navy, M.C. Report 005:341-50

Thorne, R.E., 1971 Investigations into the relation between integrated echo-voltage and fish density. J.Fish.Res.Board Can., 28(9):1269-73

3.2 Japan

Relevant research in Japan is being conducted at a number of State Fisheries Research Laboratories in association with University Departments, as follows:

(i) Institute: Far Seas Fisheries Research Laboratory
Fishery Agency
(I. Yamanaka, H. Yamanaka)

and College of Marine Science and Engineering Technology
Tokai University
(M. Nishimura)

Species investigated and sea areas: Principally tuna species in the Pacific

Acoustic equipment: Digital F type echo-counter system used with narrow beam, high resolution transducer in towed body

Status: Successful echo-counting trials conducted in Saruga Bay but system still under development and trials. Main problems and difficulties so far encountered include distinguishing targets from noise and the identification and sizing of fish targets. A new counting system with accurate noise filter is under development

(ii) Institute: Seikai Regional Fisheries Research Laboratory
Fishery Agency
(T. Aoyama)

and Faculty of Fisheries, Nagasaki University
(K. Shibata)

Species investigated and sea areas: Anchovy, sardine and mackerel in western Japanese waters including the Yellow and East China Seas

Acoustic equipment: "S type" echo integration system (Shibata et al., 1971)

Status: Successful application of system in fish abundance and school distribution and behaviour studies in Japanese waters (Shibata, Aoyama and Mimoto, 1971). Main problems and difficulties include transmission loss at high fish densities, distinguishing fish targets from "noise" (although this is facilitated by using a towed transducer housing) and errors inherent in visual method of measuring echo amplitude on the CRT display (this, however, is being automated)

(iii) Institute: Freshwater Fisheries Research Laboratory
Fishery Agency
(M. Tanaka)

Species investigated and sea areas: Landlocked salmon and pond-smelt in fresh water

Acoustic equipment: High resolution echo-sounder (SD-1005S) for shallow water use. (Transmission frequency 200 kHz: range 0-15 m; pulse length 0.65 m/sec; pulse repetition frequency 1 000/sec; paper speed 60 and 300 mm/min; power output 15.5 W)

Status: Equipment applied successfully in a number of studies

In addition to the above, research is being conducted at the Ocean Research Institute, University of Tokyo (Dr. T. Ishii) on echo-sounder "pattern analysis system" (details not supplied) in studies in the Pacific, and technical developments of acoustic equipment are undertaken at the Fishing Boat Laboratory of the Fishery Agency.

(iv) References

Shibata, K., T. Aoyama and K. Mimoto, 1971 Studies in echo counting for estimation of fish stocks. 2. An example of field survey. Bull.Jap.Soc.Sci. Fish., 37(91):825-30

Shibata, K., et al., 1971 Developments of echo-counting systems for estimating fish stocks in Japan. In: Modern fishing gear of the world, edited by H. Kristjonsson. London, Fishing News (Books) Ltd., Vol. 3:99-103

3.3 Norway

(i) Institute: The principal Norwegian centre at which research is being conducted on the use of acoustic fish detection equipment for fish abundance estimation is the Department of Fisheries, Institute of Marine Research, Bergen

Species investigated and sea areas: Capelin, herring, sprat, mackerel, blue-whiting, cod, haddock, saithe and juvenile (0-group) fish in the North Atlantic (principally Northeast Atlantic)

Acoustic equipment: Simrad scientific sounder with time varied gain circuit (either 40 logR + 2 α R or 20 logR + 2 α R), storage oscilloscope and Simrad echo integrator, which squares the voltage before integration. When the equipment is operated with the TVG function 20 logR + 2 α R, the integrator deflection is proportional to fish density within the water layer integrated, i.e., $\delta_A = CM$, where δ_A = number of fish per square mile per mm deflection; C is a constant, and M is integrator deflection in mm. The constant C varies with the size and species of fish and is determined by calibration, e.g., by counting the number of single fish within a narrow layer, either on the recording paper or by an echo-counting system. The sampling volume during calibration must be determined. The linear relationship between integrated echo intensity and average fish density holds good below certain but unknown density levels: $S_A = CM + B$

where S_A = fish density in numbers of fish per unit area
M = integrated echo intensity in mm (squared voltage)
C = constant for a given species, size and aspect

Fully controlled experiments were undertaken in 1971 and 1973 to investigate:

(a) the dependence of C on species size and aspect

(b) the density level up to which the above equation can be used without causing bias

(c) the variance of C at different densities when species and size are kept constant and the fish are allowed to change aspect as under normal swimming movements.

Literature describing the equipment and its method of application includes:

Blindheim, J. and O. Nakken, 1971 Abundance estimation of the spawning Lofoten cod. ICES Doc. B.15 (mimeo)

Bodholt, H., 1969 Quantitative measurements of scattering layers. Simrad Bull., 3:1-11

Dragesund O. and T. Monstad, 1973 Observations on capelin (Mallotus villosus) in Newfoundland waters. Redbook ICNAF, 1973(3):127-36

Gerhardsen, T.S., et al., 1968 A systematic approach to the selection of acoustic fish detection instruments for fishery research vessels. Paper presented to the Second FAO Technical Conference on Fishing Research Craft, Seattle, Washington

Midttun, L. and O. Nakken, On acoustic identification, sizing and abundance
1971 estimation of fish. Fiskeridir.Skr.(Havunders), 16:36-48

_____, Application of acoustic stock abundance estimation on capelin and
1972 blue whiting. ICES Gear and Behav.Cttee,Doc.B16:9 p.

_____, Some results of abundance estimation studies with echo integrators.
1973 Paper presented to the FAO/ICES/ICNAF Symposium on Acoustic Methods in Fisheries Research, Bergen, 1973, Paper (38):1-13

Nakken, O. and G. Vestnes, Ekkointegratoren. Et apparat for å måle fisketetthet.
1970 Fiskets Gang, 56:932-6

Status: The system has been used successfully in studies of the abundance, behaviour and migration patterns of a number of fish species. The most accurate abundance estimates are obtained when fish stock under investigation is distributed within a defined area unmixed with other species in continuous scattering layers at moderate depths in midwater. Conditions are less favourable for abundance estimation when fish form dense schools, when they are mixed with other species, and when they are close to the seabed. Towed transducers are being tried in an attempt to overcome the latter limitation. Timing of surveys for abundance estimation must therefore be chosen carefully in light of knowledge of distributional behaviour of fish. State of investigations of specific species is as follows:

(a) Cod
Survey for abundance estimation of the spawning Lofoten cod was carried out in 1971. Results are presented by Blindheim and Nakken (1971). A survey in 1972 was not very successful because the fish were distributed very close to the bottom and near land and therefore difficult to detect from a large vessel. In 1973 a new approach will be followed to estimate the stock size of spawning cod.

(b) Sprat
Surveys of Norwegian fjords are carried out in the autumn. Maps of distribution as well as relative estimates of abundance of 0-group sprat have been obtained. These estimates provide the basis for catch prognoses and allow comparisons among areas and years. Work on the conversion of the relative estimates to absolute estimates, survey design, better identification and separation of species is in progress.

(c) North Sea Herring
Acoustic methods have been used to determine distribution of herring. Due to the number of species present in the North Sea some difficulties have been encountered in assigning the correct proportion of the total integrator readings to herring. In 1973 a small area will be studied in detail in spring when the herring are found off the bottom.

(d) Barents Sea Capelin
The most favourable conditions for abundance estimation of capelin is found during the summer feeding season say during September. Surveys have been carried out both in 1971 and 1972 and stock abundance has been estimated (Midttun and Nakken, 1972).

(e) Newfoundland Capelin
The Newfoundland capelin has been surveyed and a tentative estimation has been made (Dragesund and Monstad, 1972). Investigations will be continued in 1973.

(f) Blue Whiting

The survey for estimating the spawning stock of blue whiting was carried out under ideal conditions in March 1972. The fish were mostly concentrated in well defined layers, but also in schools, of low or moderate density. The area of distribution was well defined and when compared to the distribution at other times of the year of moderate extension. Results are summarized by Midttun and Nakken (1972).

3.4 Spain

(i) Institute: Relevant research is conducted at the Spanish Government's Laboratories of the Instituto de Investigaciones Pesqueras in Barcelona (Dr. C. Bas) and Vigo (Mr. Rucabado).

Species investigated and sea areas: Sardinella, cephalopods and species of Sparidae in the Sahara and Cape Blanco Sea areas

Acoustic equipment: Simrad EK38 echo sounder with echo integrator

Status: Material collected on research vessel surveys with the equipment currently being evaluated. Difficulties encountered in identification of species on the echo records and insufficient resolution power of equipment. Acquisition of new, higher resolution equipment currently under consideration.

3.5 United Kingdom

The principal programmes of research on the use of specialized acoustic fish detection equipment in fish abundance studies are conducted at the Government fisheries research laboratories in England and Scotland. Other related research is also being undertaken by the Industrial Development Unit of the White Fish Authority, the National Institute of Oceanography of the Natural Environment Research Council, by the Admiralty Research Laboratory, by University Departments and by echo-sounder manufacturers. Their activities are summarized below:

(i) Institute: Ministry of Agriculture, Fisheries and Food
Fisheries Laboratory
Lowestoft
Suffolk, England

Investigators: D.H. Cushing
R.B. Mitson
C.R. Hood
N.D. Pearson
A.J. Burridge

Species investigated and sea areas:
(a) Capelin, cod, haddock, dogfish and O-group cod in the Barents Sea, around Iceland, the Faroes and off West Greenland
(b) Cod, haddock, sprat and sandeels in the North Sea
(c) Herring, mackerel, pilchard and horse mackerel in the Celtic Sea
(d) Hake off southwest Africa

Acoustic equipment: (a) A 30 kHz echo-sounding system, based on the Kelvin-Hughes "Humber" echo sounder coupled to a specially designed amplifier and signal processing equipment and incorporating a Simrad QM echo integrator, is used in pelagic and demersal fish studies. The transducer is mounted aboard ship or the towed housing; the latter can be attached to a special

frame so that precise calibrations are obtained. To normalize all signals, a digitally controlled, time varied gain (either 40 logR + 2 R or 20 logR + 2 R) circuit is used over the range 3–550 metres. On one channel, signals are processed by continuously variable range gates which allow selection of the required sampling interval. Individual cycles in the echo are counted to determine if it originated from a single fish or a school. By using a discriminator in conjunction with a pulse delay system, the signals from single fish are obtained separately and passed to a pulse height analyser to give distributions of signal strengths. Counts of the number of cycles from single fish and from schools are made for each range gate per nautical mile. On a second channel signals from the time varied gain amplifier are processed by the echo integrator. Normally, the method of operation is to integrate total signals per nautical mile on one section of the integrator, and on the other to integrate all signals in the range gate between transmissions.

A further 30 kHz echo-sounder system, described as MS 44 and Kingfisher II of Kelvin-Hughes manufacture, is used only in the studies of demersal fish. Signals are displayed on normal recording paper.

(b) Two 100 kHz echo-sounder systems. System 1 comprises a transducer of 13° full angle with conical beam and having a source level of 128 dB/µbar/m and range resolution of 8 cm. Signals are displayed on a 19-inch paper record. A "white-line" facility is fitted. The main use of this system is to provide good resolution so that indications of school densities and direct fish counts can be made from the paper records under some conditions.

System 2 comprises a high powered (18 kW) transmitter driving a 3° x 5° towed narrow beam transducer. Two signal processing channels are used similar to those described above for the 30 kHz system. At present only a short-range version of this system is in use, but the design and development of the system for operation over the range 3–550 metres is well advanced. It is intended that this will replace the 30 kHz equipment described under (a), giving greater range resolution and providing good detection capabilities up to a range of 600 metres.

Status: The two systems have only become fully operational in 1972 and material collected in studies conducted with them so far is currently being worked up and evaluated. Results of an earlier abundance estimation study of hake off southwest Africa have been published (Cushing, 1968). Studies directly related to the measurement of fish abundance currently in progress include:

(a) Acoustic determination of length distribution of fish, by sampling signals from single fish within a range gate. This, in effect, is the statistical application of a sonar equation to the relationship between target strength and length of fish and to the distribution of signals in angle within the specified range gate.

(b) The development of a computer programme for deriving the sampling volumes by fish size and range, the average signals from a fish of given size at any range, the pings per target of any size at any range and the expected height of targets above the seabed.

(c) The measurement of packing density of schooling, pelagic fish, using a sector scanning sonar system.

(d) The measurement of the catching efficiency of a bottom trawl for plaice, using transponding acoustic tags to the fish.

Reference

Cushing, D.H., 1968 Direct estimation of a fish population acoustically. J.Res.Board Can., 25(11):2349-64

(ii) Institute: Department of Agriculture and Fisheries for Scotland
Marine Laboratory
Aberdeen, Scotland

Investigators: R.E. Craig, S.T. Forbes, W.I. Dunn, R.G. Lawrie

Species investigated and sea areas: Herring, sprat, blue whiting and the pelagic O-group stages of gadoid species (cod, haddock, whiting, Norway pout) in the northern North Sea, off the north and west coast of Scotland and adjacent oceanic regions

Acoustic equipment: The acoustic system is based on three types of echo sounder, viz. the Simrad EK38, Simrad EK50 and a 400 kHz narrow beam, high resolution equipment developed by the Laboratory. These sounders are used with a Laben 400 channel pulse height analyser which, with suitable interfaces, can be used to size and count the echo signals, or to act as an echo integrator. Both hull mounted and towed transducers are used with the systems. Descriptions of the system are given in the following publications: Craig and Forbes, 1969; Forbes, 1970.

Status: The echo-counting system has only recently become fully operational and is currently being evaluated. Results obtained so far from preliminary surveys have highlighted the importance of reducing ship interference and noise, of accurate beamshape calibration and of increased knowledge of the target strengths of fish, by species and size, and other organisms for the range of transmission frequencies used.

References

Craig, R.E. and S.T. Forbes, 1969 Design of a sonar for fish counting. Fiskeridir.Skr. (Havunders), 15:210-9

Forbes, S.T., 1970 A quantitative fish counting echosounder. Inst.Electron.Radio Eng. Conf.Proc., 19:95-108

(iii) Institute: Natural Environment Research Council
National Institute of Oceanography
Wormley
Surrey, England

Investigators: B.S. McCartney
S.M. Rusby
A.R. Stubbs

Species investigated and sea areas: Herring in the shelf area to the west of Scotland

Acoustic equipment: Low frequency sonar in towed, underwater body

Status: The equipment has been used successfully in a recent survey of a herring fishing area to the west of Scotland. Results of this work are being prepared for publication. Associated studies have also been conducted on the target strengths of fish in dorsal aspect, together with swim-bladder resonance measurements (in collaboration with staff of the Fisheries Laboratory, Lowestoft and Marine Laboratory, Aberdeen).

(iv) Other Studies

In addition to the above detailed investigations of fish abundance using acoustic equipment, closely related research on important aspects of the subject, including specialized technique and equipment development are being produced at the following research centres:

(a) Department of Electronic and Electrical Engineering
University of Birmingham
(Professor D.T. Tucker, Dr. V.G. Welsby, Dr. H.O. Berktay, Dr. G.C. Goddard, Dr. D. Creasey)

Projects under investigation include:

(i) Measurement of fish target strength (work being done in saltwater quarry on the west coast of Scotland). The primary objective of this study is to provide accurate data on the acoustic target strength of live marine fish, with particular reference to species of commercial importance. Species studied up to the present time are cod, haddock, saithe and dog-fish. Two frequencies are being used, 30 kHz and 100 kHz at two angles of elevation, one being dorsal and the other at 22.5°. For each position and frequency, 1 000 measurements are recorded for each fish on punched tape and the analysis subsequently carried out by computer. This project, which is supported by a research grant from the Natural Environment Research Council is expected to end in autumn 1973.

(ii) Development of acoustic, fish counting system for counting salmonids in rivers. Equipment is currently under evaluation at fixed installation in River Dee, Cheshire.

(iii) Development of digital sonar system, having a continuous 60° search sector and resolution of approximately 5° in bearing and 20 cm in range. Trials have been made of a prototype system. A commercial version is currently being developed by Messrs. Marconi Marine and is likely to be marketed in the near future.

(iv) Development of short-range sector scanning sonar system, working at 500 kHz having a sector width of 30° and a bearing resolution of 1°. This is a small, portable system capable of giving information on fish behaviour, shoal density, etc., under suitable conditions.

In addition, research is being conducted on an acoustic telemetry with the aim of developing reliable, high data rate acoustic links from fishing gears (trawl) to ship.

(b) Loughborough University of Technology
Loughborough, Leicestershire
(Professor J.W.R. Griffiths, Mr. A. Pratt, Mr. A. Spencer)

Research is being conducted on a number of specialized techniques, including acoustic holography, time varied gain amplifier design, methods of driving scanning sonar transmitters at high frequency (up to 1 MHz) and high power (up to 20 kW), transducer array processing, target echo characteristics (aimed at improving identification of targets accustically) and bandwidth compression for video signals from scanning sonars.

(c) Ministry of Defence
Admiralty Research Laboratory
Teddington, Middlesex
(Dr. D.E. Weston, Mr. J. Revie, Miss P.A. Ching)

A low frequency research sonar, with a range of tens of kilometres, and with the transducer laid on the seabed has been used to record fish densities. By using echo-ranging and attenuation measurements, fish (otherwise identified as pilchard) densities of the order 5×10^4 per km^2 have been determined in the Celtic Sea during the summer months.

References

Ching, P.A. and D.E. Weston, 1971 Wideband studies of shallow water acoustic attenuation due to fish. J.Sound Vib., 18(4):499-510

Weston, D.E. 1972 Fisheries significance of the acoustic attenuation due to fish. J.Cons.Perm.Int.Explor.Mer, 34(2):306-8

Weston, D.E. and P.A. Ching, 1970 Sound extinction by fish in one-way shallow-water propagation. In: Proceedings of an International Symposium on Biological Sound Scattering in the Ocean, Maury Center for Ocean Science. Washington, D.C., Department of the Navy

Weston, D.E. and J. Revie, 1971 Fish echoes on a long range sonar display. J.Sound Vib., 17(1):105-12

Weston, D.E. and K.J. Stevens, 1972 Interference of wideband sound in shallow water. J.Sound Vib., 21(1):57-64

Weston, D.E. et al., 1971 Multiple frequency studies of sound transmission fluctuation in shallow water. J.Sound Vib., 18(4):487-98

Much of the above research in the United Kingdom is conducted in close collaboration with the Industrial Development Unit of the White Fish Authority and commercial manufacturers, notably, Messrs. Kelvin and Hughes, New North Road, Hainault, Essex (Dr. Haslett, Mr. Hopkins, Mr. Ellis, Mr. Pearce). Amongst specific projects pursued by the White Fish Authority is the development of an automatic fish counting system, aimed at predicting catches of demersal fish and at indicating catch rates during commercial fishing operations.

3.6 U.S.A.

Research on the use of acoustic fish detection equipment in fish abundance studies is being pursued by a number of Federal and state fisheries research laboratories and at University Departments. A summary of the work in progress at these centres for which information is available is given below.

(i) Institute: U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center
La Jolla Laboratory
California

Investigator Leader: Dr. Paul E. Smith

Species investigated and sea areas: Northern anchovy (Engraulis mordax) and associated species in the California current region of the eastern north Pacific, between San Francisco and Magdalena Bay, Baja California, Mexico

Acoustic equipment: A 30 hKz Simrad 580-10 horizontal, ranging sonar, 8.5 kW power with 10° beam between 3 dB down points. No automatic counting system is used; each fish school is measured from an analogue record by conventional means

Status: Two surveys have been conducted with approximately equal area covered and density of coverage. The size frequency of fish school sizes was approximately the same for both surveys. Roughly 60 percent as many schools were detected on the second survey as on the first. Special studies were conducted on the approximate target strength and state of compaction of the fish school. Initial attempts at using commercial purse seiners to verify the biomass and species identity proved useful. Aerial overflight comparisons have not been successful, but overflight has guided the research vessel to concentrations of schools. The feasibility of using broadband sources and resonant frequency structure in the target return has been demonstrated from a stopped ship and preliminary trials of a towed broadband source have shown limited success. Data on doppler structure have been collected at sea and are presently undergoing analysis. Doppler structure due to gross movements of the school has been recorded, but data on doppler structure due to fish movements within the school and due to fish tail and head motions have not yet been analysed. The main limitations of the present system for accurate measurement of fish abundance include:

(a) Fish school counting: The major barrier to fish school counting is that the estimates of transmission loss between the sonar and the target are not well enough defined to delimit the area effectively insonified so that the targets received can be extrapolated from the area sampled to the whole area. Similarly, target strength is difficult to evaluate under these conditions. Another important barrier to quantitative work is lack of knowledge of surface and bottom reverberation under differing sea states and bottom depths.

(b) Fish school biomass: The main limitation is one of real time data handling and reduction. For an accurate estimate of school biomass, one needs to record data at 500 microsecond intervals, assemble echo level information for periods as short as three seconds and as long

as 30 seconds, prepare summaries of within school propagation loss, probable transmission loss, pulse to pulse echo level variance, within pulse echo level variance, and ship motion in pitch, roll and heave. One further problem, which is not likely to be resolved, is that most fish schools are about 20 metres in diameter, but some fish are in schools 50 metres or so in diameter. The former size school can be captured in its entirety to confirm biomass estimates; the larger schools cannot be entirely captured by existing gear. We plan to use extrapolation of tonnage per unit echo level per unit horizontal school surface from smaller schools to larger and compare these estimates with experienced airborne observer estimates.

(c) Sizing of fish within schools: The main limitation is to get sufficiently powerful broadband sources (such as arcers) which can be towed at moderate ship speeds. Here again, there is a data handling problem. Real time spectral analysis is now relatively easily done, ensemble averages can be automatically taken. Information on ship's motion at the time of each pulse and the reception of each portion of the target must be logged. While none of these is difficult to obtain accurately, this information adds to the problem of receiving, processing, analysing and storing data.

(d) Fish school identification: The limited observations made so far suggest that fish species in this area are often mixed within schools. This means that species will have to be identified and the proportions fixed. The acoustic properties of feeding, breeding and migrating fish schools will be different and the species like anchovy, sardine and jack mackerel will be indistinguishable acoustically when feeding or migrating.

Specialized studies and developments currently in progress, aimed at increasing the efficiency of the acoustic system include the following:

(a) the development of a variable depth sonar system, spectral analyser and computerized data processor;

(b) studies of (i) a sound velocity profile system which specifies by range and depth the probability of observing a -30 dB schooled target,

(ii) a biomass analysis system which uses range, apparent target strength and within school attenuation, to estimate the state of compactness of the fish school,

(iii) a fish sizing system, which uses resonant frequency of return, if any, to estimate fish gas bladder size, or doppler shift to estimate swimming speed.

(ii) Institute: State of California
Department of Fish and Game
Marine Resources Region
California State Fisheries Laboratory
Long Beach, California

Investigator Leader: Dr. K. Mais

Species investigated and sea areas: Principally the northern anchovy (Engraulis mordax) in the California current system from California coast to Baja California, Mexico

Acoustic equipment: (a) Simrad SK3 horizontal ranging sonar
(b) Simrad EK38 vertical echo sounder (beam widths 13° x 20° and 7° x 20°) with Ocean Sonics Model 119T precision depth recorder and Hewlett Packard 141B oscilloscope

Status: Good estimates have been made of the relative abundance of northern anchovies, Engraulis mordax, between various regions of the California current system. Surveys have produced good distributional data both in time and space and furnished valuable information on behaviour and availability. Results of the first five years of this work will be published in 1973. Hull-mounted equipment performs inefficiently in poor conditions of large swells and rough sea surface. Also the refraction of sonar beams by extremely varied thermal stratification makes it difficult to determine insonification area. Unwanted bottom echoes from sonar operation in shallow rocky areas make enumeration of fish schools difficult. Quantification of fish schools from acoustic records is at present an educated guess.

Comparison of acoustically derived school dimensions and target strengths with actual catches by commercial purse-seine vessels will be made for quantifying anchovy schools.

The main equipment limitation is quantification of schools or groups of fish. The chief survey technique problem is the extremely varied schooling behaviour of anchovies and other pelagic fishes which ranges from no schooling whatsoever to highly compact definite school formation. Also the patchy distribution of the various species greatly complicates determination of survey areas and intensities. Estimates of abundance on this type of distribution are subject to very large statistical error.

(iii) Institute: University of Washington
Seattle
Washington

Research involving cooperation between the Fisheries Research Institute of the College of Fisheries, Applied Physics Laboratory, the Division of Marine Resources and the Department of Electrical Engineering and Oceanography of the College of Arts and Sciences.

Investigators:
W.C. Acker (Applied Physics Laboratory)
H.R. Feldman (Applied Physics Laboratory)
J.E. Ehrenberg (Applied Physics Laboratory and Division of Marine Resources)
J.H. Green (Applied Physics Laboratory and Division of Marine Resources)
D.E. Lytle (Professor, Electrical Engineering)
S.R. Murphy (Director, Division of Marine Resources; Professor of Oceanography and of Mechanical Engineering)
R.E. Thorne (Fisheries Research Institute, College of Fisheries)

Species investigated and sea areas: Principally stocks of hake in Puget Sound, juvenile and adult sockeye salmon in Lake Washington, juvenile sockeye salmon in several other Washington State waters, Bristol Bay, Alaska and Fraser River, British Columbian lakes, and Pacific herring in Puget Sound and southeastern Alaska

Acoustic equipment and Status: A principal part of the original Sea Grant Marine Acoustics Program proposal was the development, application and evaluation of an analogue echo integrator. This was a cooperative undertaking by the Fisheries Research Institute and the Department of Electrical Engineering. An integrator was built during the summer of 1968 (Lahore and Lytle, 1970). From August 1968 to April 1969, field tests of the integrator for the purpose of establishing the relationship between integrated voltage and fish density were conducted on Lake Washington juvenile sockeye salmon (Oncorhynchus nerka) and Pacific hake (Merluccius productus) and Pacific herring (Clupea harengus pallasi) in Puget Sound. Subsequently, the integrator was used to estimate the abundance of presmolt sockeye salmon population in Lake Washington and spawning hake in Port Susan, Puget Sound (Thorne, 1970; Thorne and Woodey, 1970; Thorne, 1971; and Thorne, Reeves and Millikan, 1971). The integrator was also used by the National Marine Fisheries Service, Seattle, during a cooperative U.S./Soviet survey of the Pacific hake stock off the Vancouver Island/Oregon coast during the summer of 1969.

As a result of these experiences, an expanded programme was initiated in 1970, having the following main objectives:

(1) theoretical analysis and modelling of variance sources for acoustic assessment techniques;

(2) continued development of data acquisition and processing systems;

(3) continued practical application to gain real world experience with problems of fishery resource assessment and to provide data for upgrading the theoretical models.

The Applied Physics Laboratory became the focal point for hardware and software development, the Department of Electrical Engineering and the Applied Physics Laboratory for the theoretical analysis of signal processing techniques and the Fisheries Research Institute for the field application of acoustics systems, and the evaluation of system performance relative to the needs of fisheries research and management investigations.

Detailed theoretical studies of echo signal processing methods were initiated in 1970 to examine the sources of variability associated with echo integration, and to compare the integration technique with echo counting and other techniques (Ehrenberg and Lytle, 1971; and Moose and Ehrenberg, 1971). A comprehensive analysis of the echo signal processing problem has subsequently been completed. At present the theoretical studies are concentrating on methods of extracting target strength distributions from echo strength distributions.

The direction established by the theoretical analysis and the success of the analogue integrator prompted the development of a more versatile integrator system. Consequently, a digital data acquisition and processing system (DDAPS) was constructed. This system has been used in a wide variety of fish abundance estimation studies. The system is built around the small general purpose PDP/8L computer manufactured by the Digital Equipment Corporation. The use of a digital system eliminates the disadvantages of analogue systems such as instability and limited dynamic range. The DDAPS, which is programmed to operate as a 20-channel echo integrator, can simultaneously process data from up to a 10-depth stratum from each of two sounders. Also, it includes an automatic bottom-tracking routine which terminates integration a predetermined distance above the bottom (Moose, Ehrenberg and Green, 1971; Moose, Thorne and Nelson, 1971). Hardware additions to the system not described in the above papers include a buffer core memory, tape storage unit and tape controller, a line printer and CRT display. These additions, together with a cross-assembler programme used with the CDC-6400 computer, have greatly reduced input/output time and facilitated programme preparation. A large system based on a PDP 11/45 is presently under development.

Other systems developed under the programme include a free-floating echo-counting system and a portable acoustic data acquisition system. The system consists of an upward-looking 250 kHz transducer suspended on a coaxial cable from a free-floating buoy. The buoy houses the transmitter/receiver unit and a radio transmitter which links the system with a monitoring ship containing a multichannel receiver and digital recorder. The monitoring ship can receive data from up to six buoys. In its present configuration the system is designed to record targets occurring between the surface and a depth of 30 metres. This is the depth range in which salmon usually migrate at sea and in which, at the indexing sites, few other species of fish, particularly species as large as salmon, are found. The system is designed to replace purse seining as a method of indexing salmon abundance, although some seining will be necessary to determine the species and age composition of salmon being monitored. Preliminary field tests have been completed which demonstrated that in moderately rough seas the system can be satisfactorily handled and can achieve a reliable telemetry range of 15 miles. A low frequency (2-4 MHz) telemetry system is being developed to increase the range to 40-60 miles. Excellent results have been achieved with known fish populations. During the summer of 1973, several buoys will be deployed off Adak Island, Alaska, in a major test of the system's operational effectiveness (Acker, 1973).

The portable quantitative data collection system developed under the Marine Acoustics Program has been used on vessels as small as 16 feet in length. It consists of a 105 kHz Ross echo sounder, which was equipped with an isolation amplifier and an internal calibration oscillator, a transducer mounted on a towed vehicle, and an analogue magnetic tape recorder with an interface for converting the acoustic data to a frequency compatible with the tape recorder. The entire system is monitored with an oscilloscope and is powered by a 12 V battery in conjunction with inverter. Much of the data recorded on magnetic tape is processed in the laboratory with the DDAPS system.

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3.7 U.S.S.R.

Institutes: Research on the use of acoustic equipment for fish abundance estimation has been conducted by the Soviet Fisheries Research Laboratory (VNIRO) in Moscow and at the regional laboratories on the Atlantic and Pacific coasts.

Species investigated and sea areas: Herring and gadoid species in the Norwegian Sea; capelin, cod and haddock in the Barents Sea; salmon in the Okhotsk Sea; ocean perch off the Pacific coast of North America

Acoustic equipment and Status: In earliest investigations, standard vertical echo sounders used in association with narrow beam sounder and underwater photography to measure density. This equipment first used to estimate population size of Atlanto-Scandian herring in the Norwegian Sea (Truskanov and Scherbino, 1966). Estimates obtained over a number of years agree well with independent estimates from other data (e.g., from analysis of tag recaptures). Since 1970 stereophotography has been used in association with the echo-sounder system, and this has greatly increased its overall efficiency and the accuracy of abundance estimation, especially in mixed species situations, e.g., for herring in the presence of gadoid species.

An echo-integrator system developed at the PINRO Institute is now used with a wide beam SIMRAD EK-12 echo sounder and a narrow beam EK-120 sounder to estimate abundance of dispersed fish concentrations, e.g., of gadoid species (Birdichevsky and Tesler, 1969)

Horizontal ranging sonars have also been used for determining stock distribution, movements and abundance of schooling (herring) and non-schooling (salmon) pelagic fish concentrations. Estimates of the numbers of pre-spawning salmon in coastal waters along the Kamchatka coast have been made using a HAG-400 sonar. Attention is now being given to the development and use of continuous emission FM and sector-scanning sonars for abundance estimation.

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3.8 FAO Field Project Activities

In 1968 a decision was made in FAO to start to utilize echo-counter systems within the framework of UNDP/FAO field project activities. Echo-integration equipment + scientific sounders, etc., were ordered from SIMRAD for purchase in Peru, Argentina and West Africa. Unfortunately, first results were disappointing mainly due to lack of expertise on the part of scientists involved in the work, and also lack of detailed instruction manuals, etc.

In 1970, however, a successful survey was carried out in the Black Sea and the Sea of Marmara in Turkey and significant estimates were obtained of fish abundance in the area. A new approach was utilized in that instead of determining target strength or estimating the integrator level by counting individual fish recordings from the paper record, an integrator calibration method was evolved whereby live fish were held in a cage moored below the transducer and varying numbers of fish were integrated. This gave an integration regression of fish number over electrical voltage which could be extrapolated over a survey area. Continuous test fishing for target identification was carried out. Further successful surveys have been carried out in Peru, Brazil, Morocco, Algeria, Tunisia, South West India and Lake Tanganyika (Johannesson, 1973; Johannesson and Robles, 1973; Johannesson, 1974). In addition, some further work has been done on the statistical implications of the methodology (Bazigos, 1974).

The programme is expanding and FAO hope to have a Regional Acoustic Research Centre under FAO/Government Cooperative Programme financing (FAO/NORAD), in Peru in 1975. This will involve three experts + equipment + a simulation laboratory for three years. It will be available to all Latin American Member Nations. It is hoped that this will provide a major breakthrough in technique and methodology for the area.

Future plans may include a similar laboratory for the Mediterranean, North Africa and Near East area and two posts based in FAO Headquarters, Rome, to service other projects with portable equipment (SIMRAD EK-38, calibration kit, echo integrator, etc.).

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3.9 Other Investigations

In addition to the above developments and applications of sophisticated acoustic equipment for fish abundance estimation, echo sounders and sonars are being widely used for the study of fish distribution, behaviour and relative abundance in other parts of the world. The use of echo-sounder survey techniques as part of Peruvian anchoveta studies is a particularly notable example, the multi-ship "Eureka" surveys constituting one of the most intensive applications yet undertaken.

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4. SUMMARY

The above brief survey indicates that intensive acoustic equipment development work and research on its use to measure abundance of fish is under way in a number of countries and that some estimates of absolute abundance have already been obtained using these methods (e.g., of capelin and blue whiting by Norwegian workers, of Atlanto-Scandian herring and Pacific salmon by Soviet workers and of hake off South Africa by English workers). Clearly the most suitable situations for such work are for single species of pelagic fish populations occupying well defined (preferably small) areas and having a dispersed distribution in which the packing density is not too great.

Despite the promising results obtained so far it is clearly evident that the application of the equipment currently available for estimating abundance, especially of individual species within a mixed species community, is subject to a number of limitations and shortcomings. Important amongst these are the following:

(a) The inability of the acoustic equipment to provide in most situations reliable identification of the targets giving rise to the recorded echoes. This is a major problem in multi-species situations. At present, direct sampling by fishing gear and/or observation by underwater photography and TV are the only effective ways of identification in these situations.

(b) The lack of information on the target strengths of individual fish, not only of the different species and sizes of fish within the survey area for which abundance estimates are required but also of other organisms within it which give rise to unwanted echoes. This problem is of major importance with echo-integration techniques. Where target strengths are not known, density measurements must be made by other methods, i.e., by using high resolution echo-counting equipment, or by direct photographic observation.

(c) The lack of precise information on the beam shape of the transducer transmission pulse, which limits the accuracy of measurement of its sampling volume. Intensive studies of this problem are in progress in a number of countries.

(d) The occurrence of "noise" from numerous sources and the lack of routine or automatic methods of measuring it. Amongst methods currently in use to reduce aeration "noise" in hull mounted transducer systems is to mount the transducers in towed streamlined bodies.

The solution of these and other problems is currently to the forefront of the research being conducted in a number of countries. In addition, increased attention is being given to the statistical aspects of echo-survey design and operation which govern the accuracy and precision of abundance estimation. In this respect, an important requirement in the use of echo-survey methods, which has tended to be neglected hitherto, is proper calibration of the acoustic equipment.

APPENDIX I

Composition of ACMRR Ad Hoc Group of Experts

Convener:	B.B. Parrish Marine Laboratory Aberdeen, Scotland
Technical Secretary:	D.F.S. Raitt FAO Rome, Italy
Members:	S. Paulowich Bedford Institute Dartmouth Nova Scotia, Canada
	G. Freytag Institut für Fangtechnik Hamburg, Germany
	Y. Maniwa Fisheries Agency Tokyo, Japan
	K. Shibata Nagasaki University Nagasaki, Japan
	L. Midttun Institute of Marine Research Bergen, Norway
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	R.E. Craig Marine Laboratory Aberdeen, Scotland
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